Clean Diesel Requirements and Voluntary Initiatives

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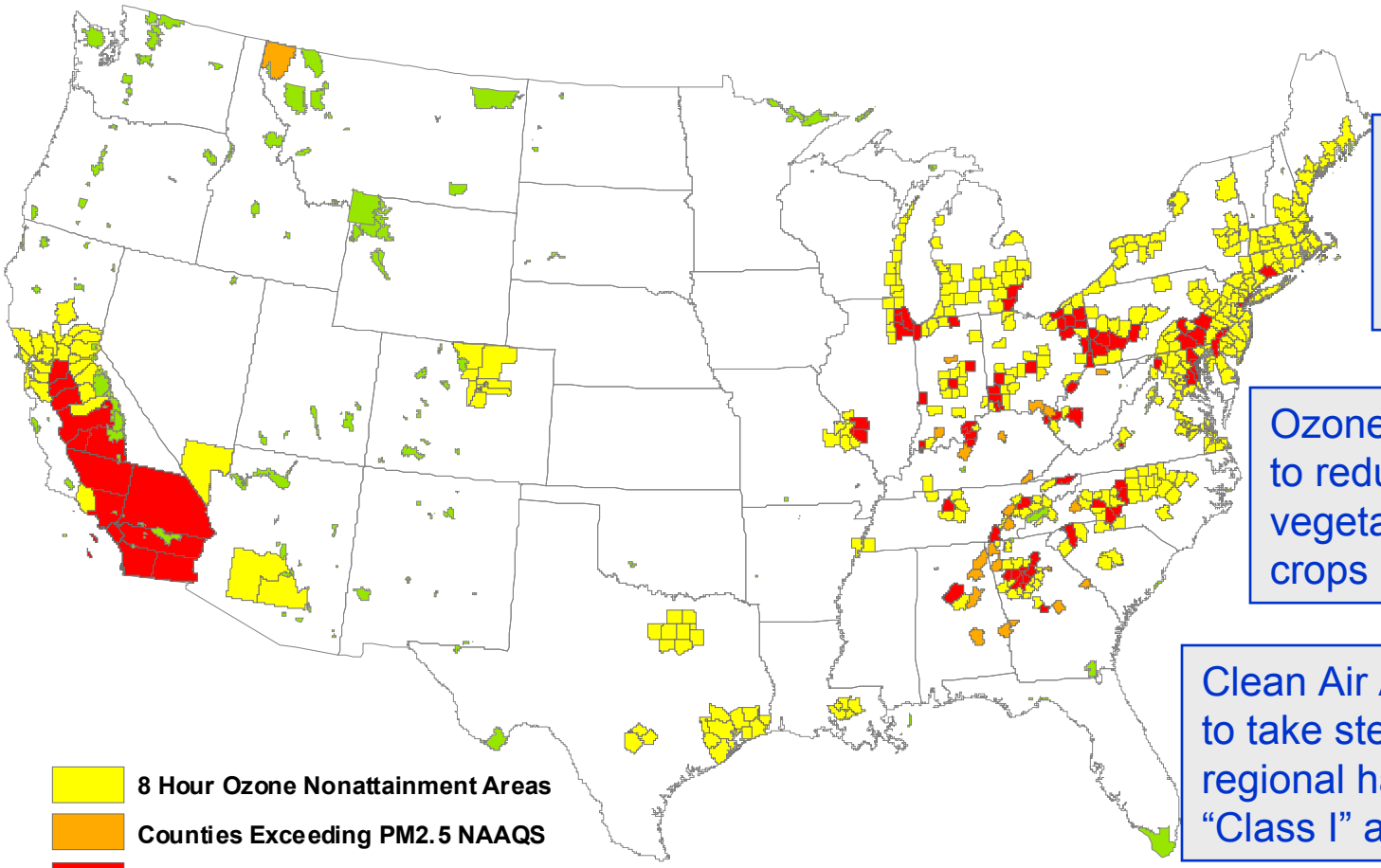
Need for Air Pollution Reduction

Fine particles from diesel exhaust can remain in the atmosphere for weeks, and carry over hundreds of miles



Diesel exhaust is likely to be carcinogenic to humans

Ozone has been shown to reduce yields of vegetables and field crops

Clean Air Act requires EPA to take steps to remedy regional haze in 156 pristine "Class I" areas

Air quality data derived from AQS (PM 2.5: 2000-2002 data; 8 Hour Ozone: 2001-2003 data) with data handling per Agency guidance.

Regulatory Strategy

New Standards for NEW diesels

Diesel engines in all mobile source applications--

- ***Regulations adopted; now focused on implementation:***

Heavy-duty trucks & buses

Nonroad machines

Light-duty vehicles

- ***Rulemakings underway for:***

Locomotives

Marine vessels

Ocean-going ships

- **Current Regulations**
  - **Very large public health and environmental benefits will result:**
    - By 2030, PM reduced by ~250,000 tons/year, NOx by ~4 million tons/year
    - Annual benefits expected to exceed $150 billion, with a cost of approx. $7 billion
  - **15 ppm sulfur cap gets immediate PM and SOx reductions from existing fleet of diesels**
    - Highway (2006)
    - Nonroad (500 ppm in 2007, 15 ppm in 2010)
    - Locomotive and marine (500 ppm in 2007, 15 ppm in 2012)

A New Approach to Clean Air Programs for Mobile Sources

- In the past, EPA created separate programs for vehicle emission standards and cleaner fuels
- The new 2007 diesel program and the nonroad diesel program take a systems approach (vehicle & fuel) to optimize costs and benefits
- Also considers the inter-relationship with other programs (like gasoline desulfurization)

Key Elements of the Engine & Vehicle Program

- Applies new NOx and PM standards to heavy-duty engines and vehicles
  - 90%+ emission reductions—gasoline-like levels
  - Based on high efficiency emission control devices (like passenger vehicle catalysts)
  - Phase-in of NOx standards 2007-2010
  - Incentives for early technology introduction

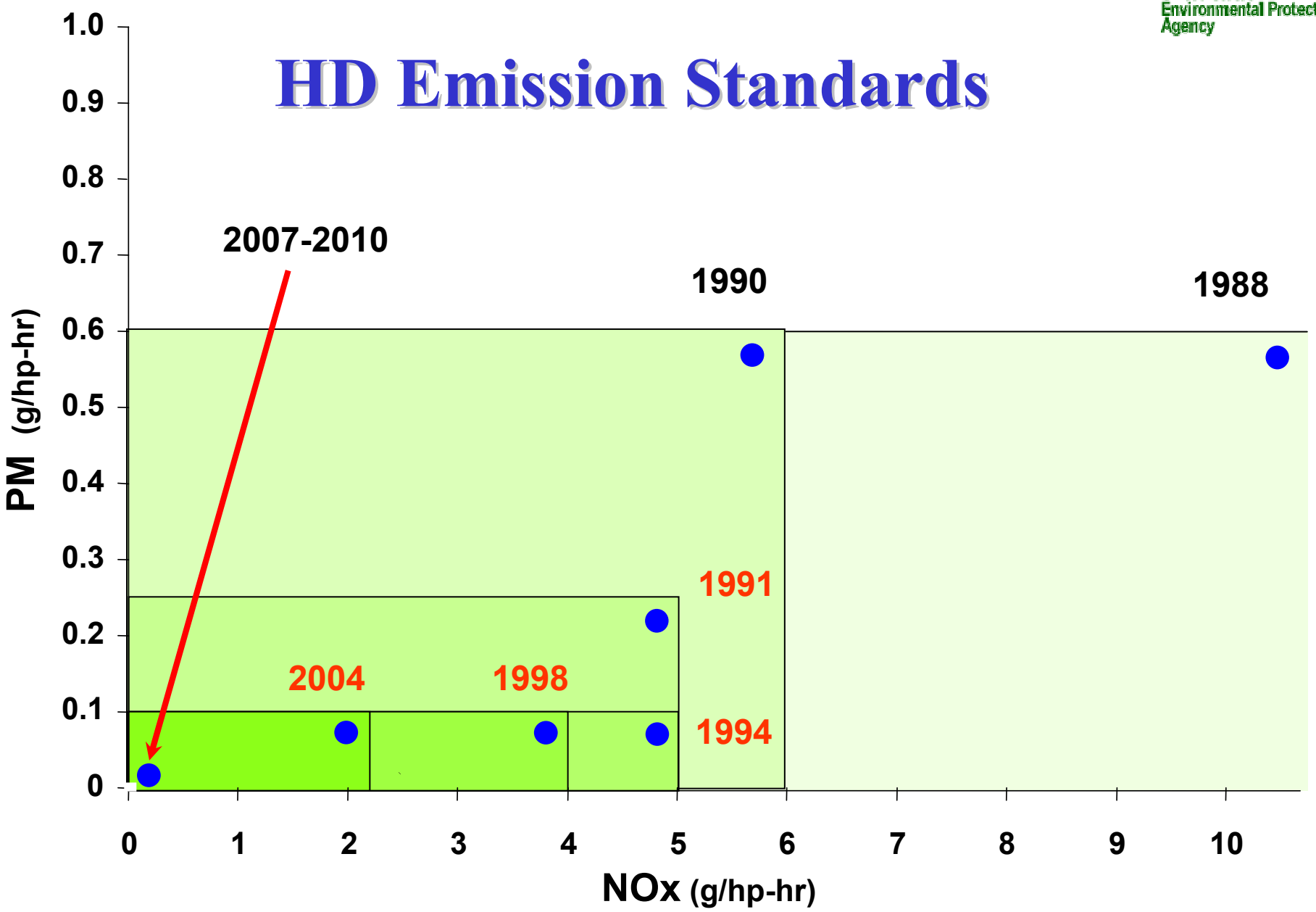
Key Elements of the Fuel Program

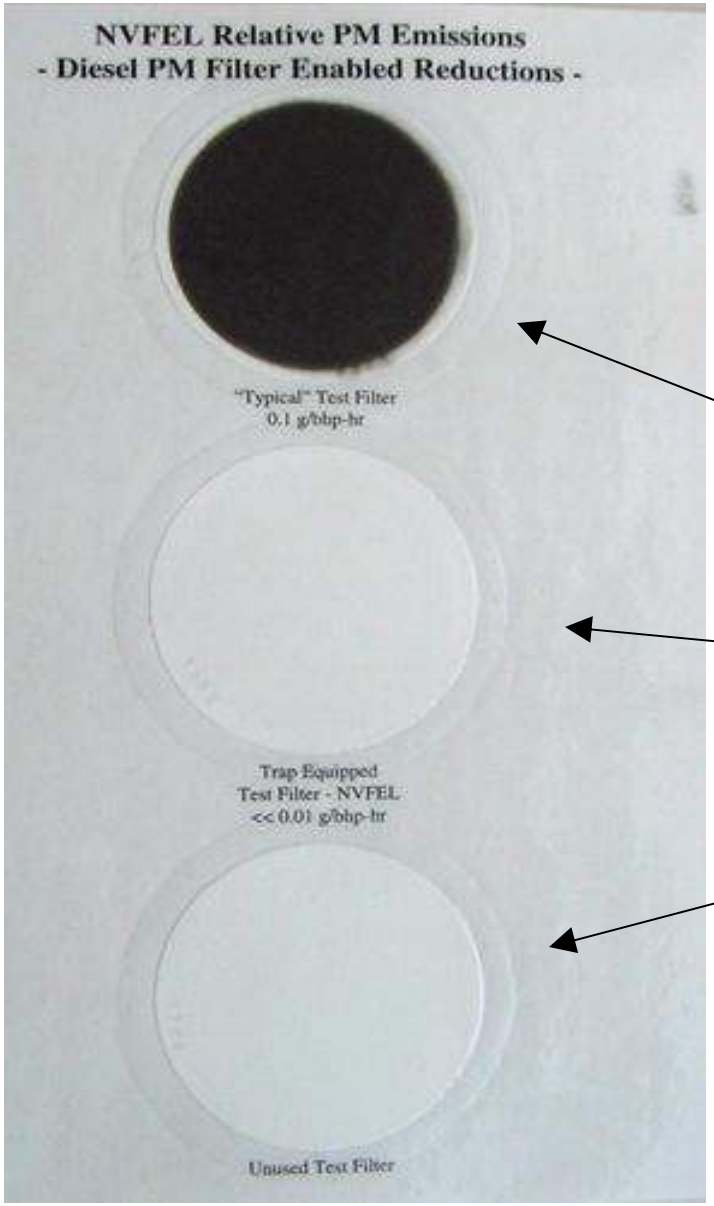
- Reduces diesel fuel sulfur levels nationwide
  - Enables use of advanced emission control technology
  - Highway diesel fuel sulfur cap of 15 ppm
    - 80% by 2006
    - 100% by 2010
  - Flexibility for small and Western refiners

Basic Program Requirements

	2006	2007	2008	2009	2010	2011	2012
PM		**100%** at **0.01** g/hp-hr					
NOx			**50%** at **0.20** g/hp-hr			**100%** at **0.20** g/hp-hr	
Fuel		**80%** at **15 ppm maximum sulfur** (under temporary compliance option)				**100%** at **15 ppm**	

HD Emission Standards





PM Emissions with Trap

- Typical test filter – current standards
- Test filter – 2007 standards
- Unused test filter

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Clean Air Nonroad Diesel Rule

- **May 11, 2004**
- **Exhaust emission standards apply to diesel engines used in most kinds of construction, agricultural, and industrial equipment**
  - **Excludes diesel engines used in locomotives or marine vessels**

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Nonroad Program Requirements

Rated Power	First Year that Standards Apply	PM (g/hp-hr)	NOx (g/hp-hr)
hp < 25	2008	0.30	-
25 ≥ hp < 75	2013	0.02	3.5*
75 ≥ hp < 175	2012-2014	0.02	0.30
175 ≥ hp < 750	2011 - 2013	0.01	0.30
hp > 750	2011 - 2014	0.01	0.30

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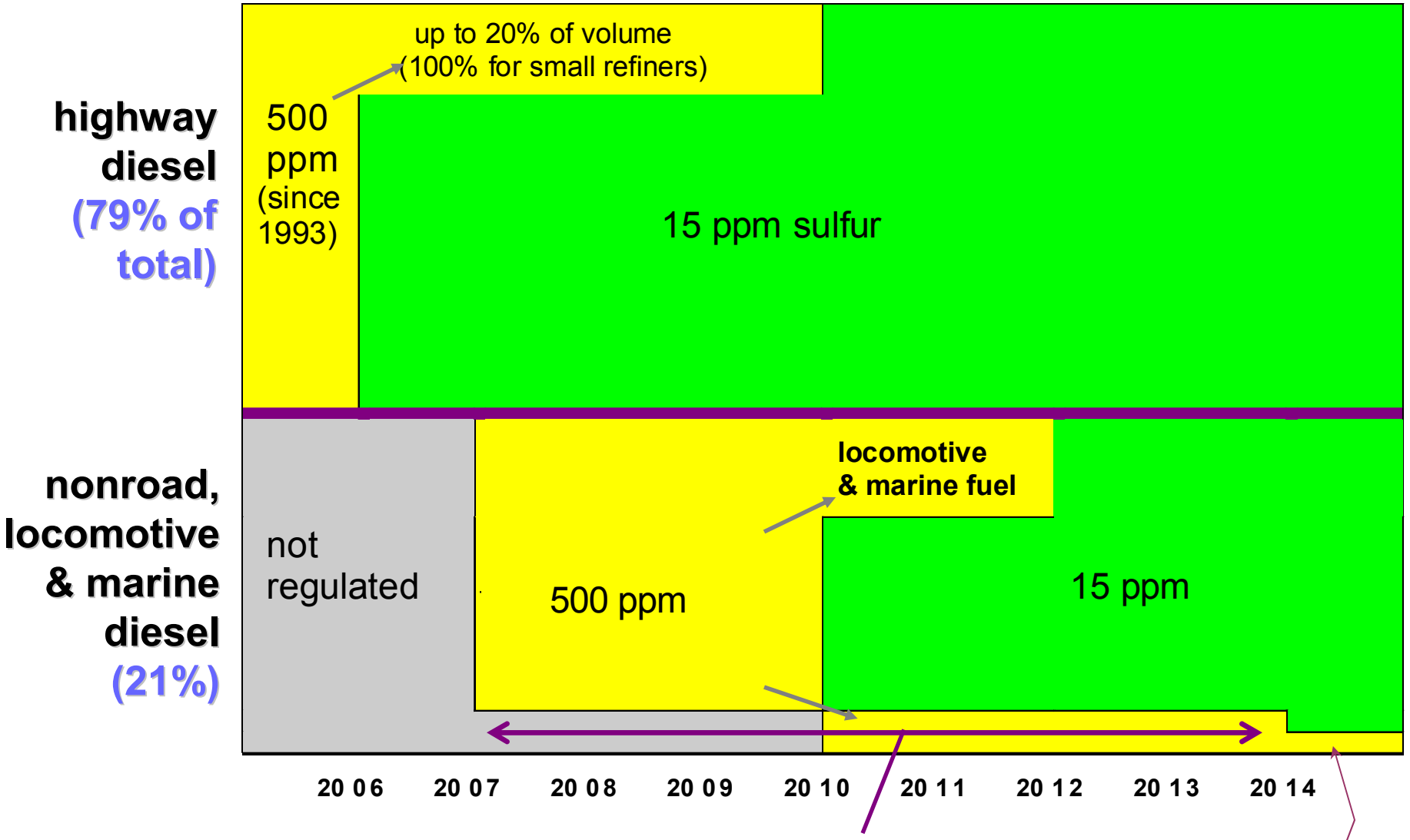
Nonroad Diesel Rule Fuel Provisions

- 500 ppm cap on sulfur in 2007
  - for all nonroad diesel fuel including locomotive and marine applications
- 15 ppm cap on sulfur in 2010
- 99% reduction from current levels (~3,400 ppm)

Sulfur in Diesel Fuel

Regulations apply June 1 at refinery, Aug 1 at terminal, Oct 1 at retailer



for transmix, small refiner fuel, and thru use of credits, except in Northeast & Alaska
(expiration date not yet set for 500 ppm locomotive & marine transmix)

National Clean Diesel Campaign

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- **Regulations for new engines**
  - Heavy-Duty Highway, Nonroad, Light-duty Tier 2
  - Upcoming standards for Marine/Locomotives
- **Voluntary Programs to address existing diesel fleet**
  - Voluntary Diesel Retrofit Program – Midwest Clean Diesel Initiative
    - Projects involving: diesel exhaust catalysts, particulate filters, engine modifications, cleaner fuels, idle reduction
    - Project evaluation, Communications & Outreach
  - SmartWay Transport
    - Projects involving: idle reduction, tires, logistics, lubricants, aerodynamics, speed management, ECM reflash
    - Communications & Outreach

Goal: By 2014 reduce emissions from the over 11 million engines in the existing fleet

The 5 Rs + Operational Strategies

- Refuel- Use of advanced diesel fuels, i.e. ULSD can lower emissions

- Retrofit- Installation of exhaust aftertreatment devices such as Diesel Oxidation Catalyst (DOC), Diesel particulate filters (DPF), etc

- Repair/Rebuild- regular engine maintenance plays a critical role in maintaining emissions performance while engine rebuilding can upgrade emissions performance of older engines.

- Repower – replacing older engines with newer cleaner engines

- Replace- replacing the entire equipment to ensure that your new purchase utilizes the most cost effective emission reduction technology

- Operational Strategies- utilizing various strategies to reduce idling

Refuel

- Low sulfur fuels: Ultra low sulfur diesel (ULSD): 15ppm
- EPA highway diesel (a.k.a., low sulfur diesel or LSD): 500ppm
- CARB highway diesel: 150ppm
- Emulsified Diesel - NOx (9-20%), PM (16-58%)
- Biodiesel
- Compressed Natural Gas (CNG), Liquefied Natural Gas (LNG)
  - inherently cleaner
- Liquefied Petroleum Gas (LPG or propane)
  - Can reduce N0x and CO

Fuels -- ULSD

- Enabler for the application of advanced PM and NOx aftertreatment technologies
- Modest PM Reductions (5 to 7%)
- Easy to use “fill & go” technology; No engine modifications needed; Utilize existing fueling infrastructure;
- Path for mandated ULSD in 2006 (nonroad in 2008)
- No performance issues or fuel economy penalties;
- Incremental cost differential;
- Reduced lubricity overcome with additives
- Potential contamination issues with higher sulfur fuels at refinery and distribution points until federally mandated ULSD program takes effect.

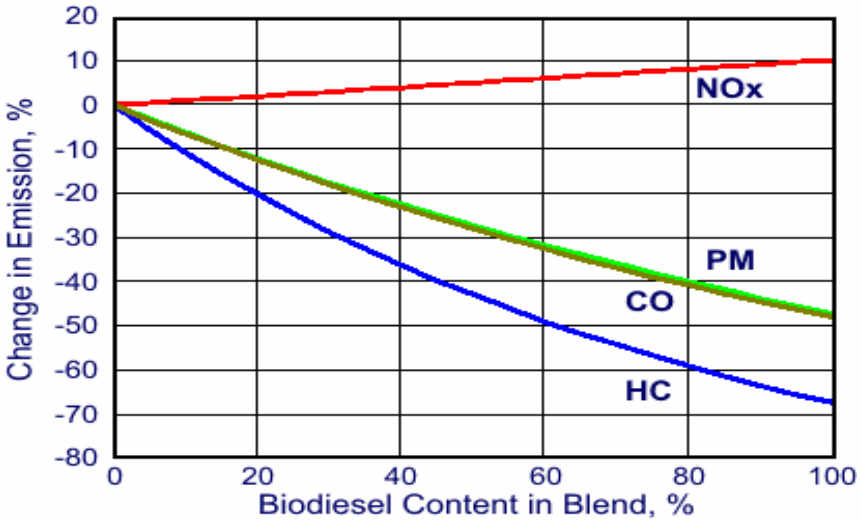
Fuels – Emulsified Diesel

- Improved atomization of fuel mixture during injection
- Increased ignition delay; increased pre-mixed combustion
- Higher combustion temperature & pressure => less PM (16-60%)
- Water cool combustion process => less NOx (9-20%)

Fuels -- Biodiesel

- No sulfur or ultra low sulfur content
- No aromatics contents (and no PAHs)
- About 11% oxygen content (petrodiesel contains no oxygen)
- Higher cetane value (typically 45-60)
- Lower heating value
- Better lubricity
- Higher viscosity
- Higher freezing temperature

COST = 10 – 50 cents/gal.



Retrofit

- Existing emission controls systems can greatly reduce diesel particulate matter (PM) emissions
  - Diesel oxidation catalysts and diesel particulate filters
- Existing and developing emission control systems can greatly reduce NOx and PM emissions
  - Lean NOx catalysts, EGR, SCR and combined systems
- Technologies to control crankcase emissions

Retrofit Technology Verification

- Objective: Evaluate the emission reduction effectiveness of retrofit technology

  - Verification provides stakeholders with confidence that these technologies will achieve quantifiable emission reductions

- Verification consists of the following:
  - Appropriate Testing Protocols
  - Statistical Sampling Methods
  - Durability Requirements

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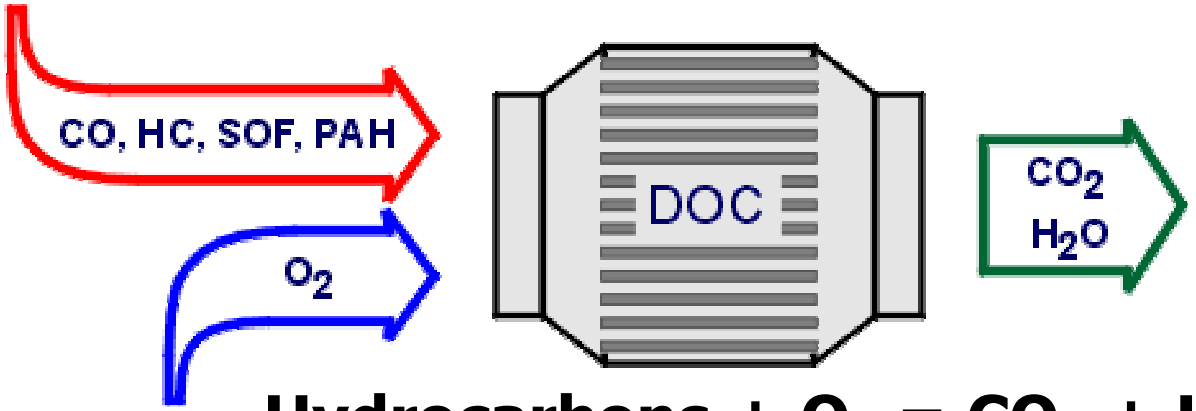
Diesel Oxidation Catalyst (DOC)

- DOCs are devices that oxidize pollutants in the exhaust stream and can be packaged with mufflers.
  - Most widely used technology to date
  - Applicable to virtually all engines and vehicles
  - No maintenance required
  - Can reduce PM emissions by 25-50% depending on fuel sulfur and the soluble organic fraction of PM

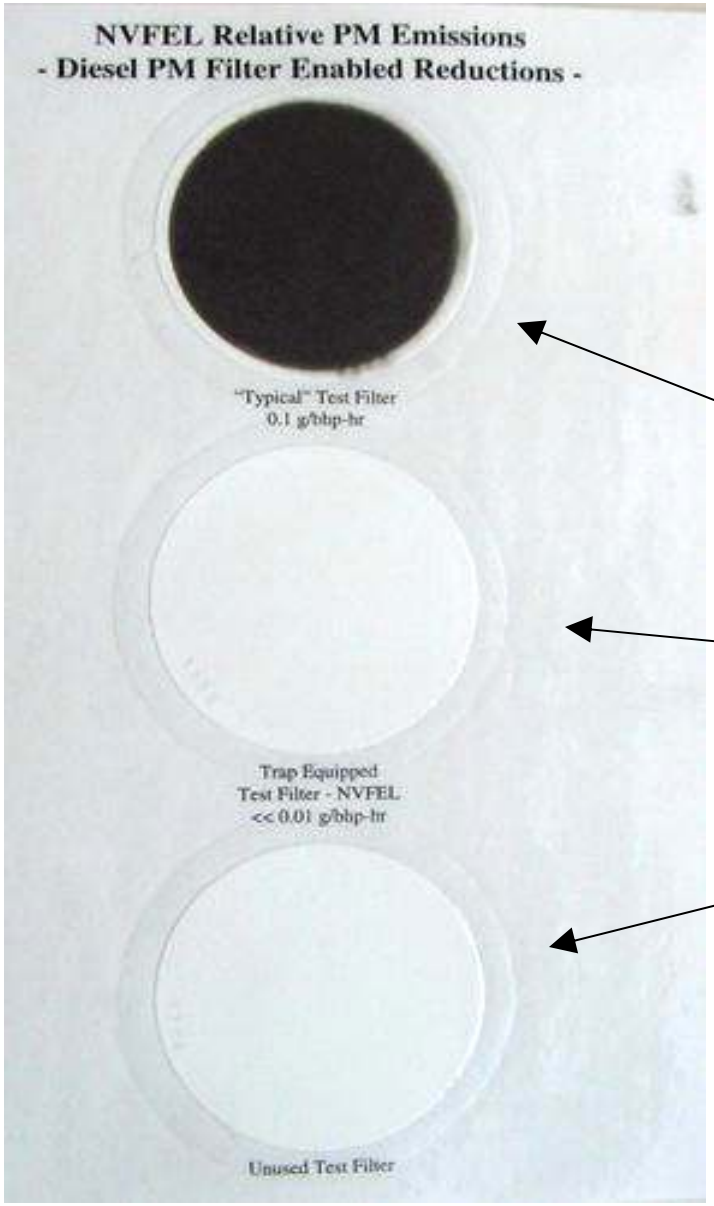


Hydrocarbons + O_2 = CO_2 + H_2O

CO + ½ O_2 = CO2

Diesel Particulate Filter (DPF)

- DPFs are honeycomb or mesh devices placed within the exhaust stream that physically trap and oxidize PM.
- Widely applied, but some applications (due to low exhaust temperature) require active regeneration, which is not yet practical for some existing vehicles



PM Emissions with Trap

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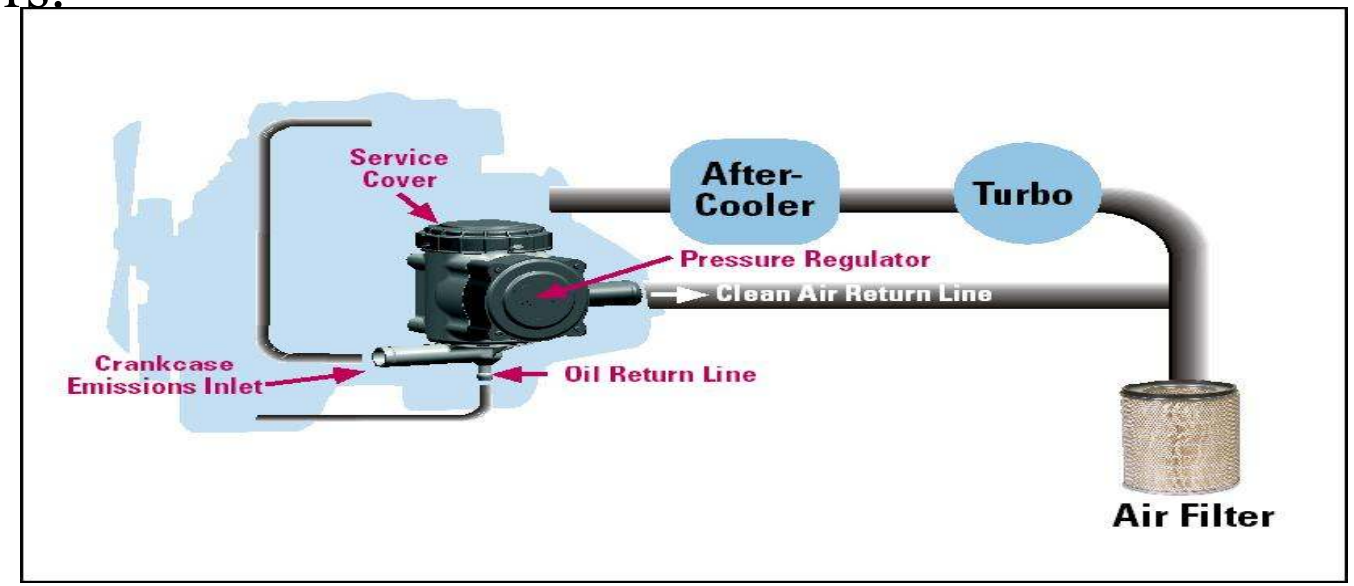
Closed Crankcase Ventilation (CCV)

- In many diesel engines, crankcase emission or “blow-by” are released directly from the engine
- CCV devices provide a cleaner engine environment by capturing and returning oil in blow-by gasses to the crankcase.
- CCV devices direct NOx, HC and toxics to the intake system for re-combustion instead of polluting the environment.
- PM is collected in a filter and removed from the crankcase vapors.



Selective Catalyst Reduction (SCR)

- SCR Systems inject urea (or some form of ammonia) into the exhaust stream and react over a catalyst to reduce NOx emissions.
- Due to reductant storage requirements, use has been limited to large engines (e.g., ships, locomotives, stationary equipment), but capable of 60-90% reduction

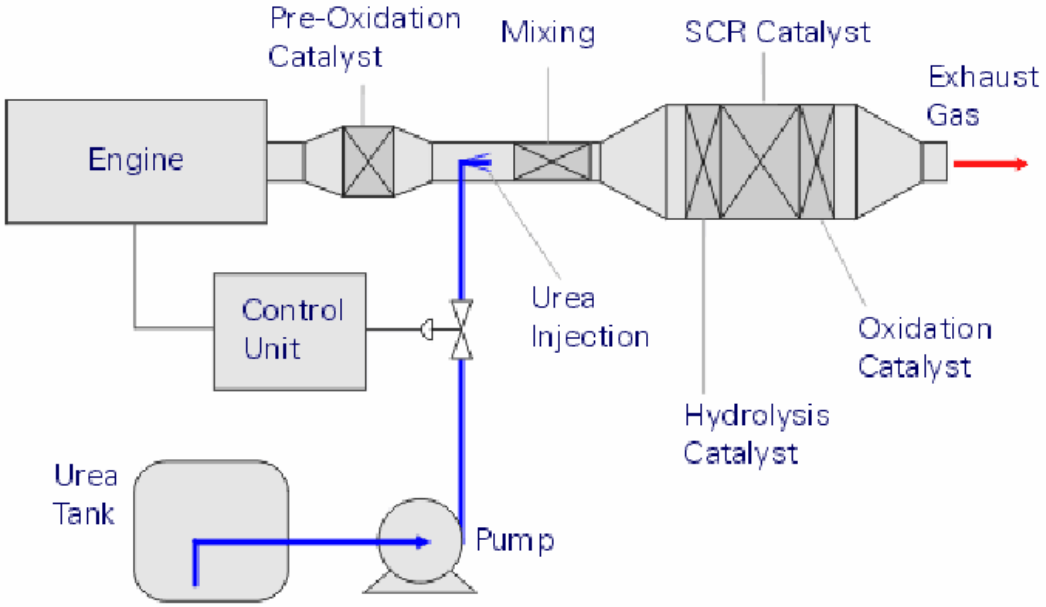
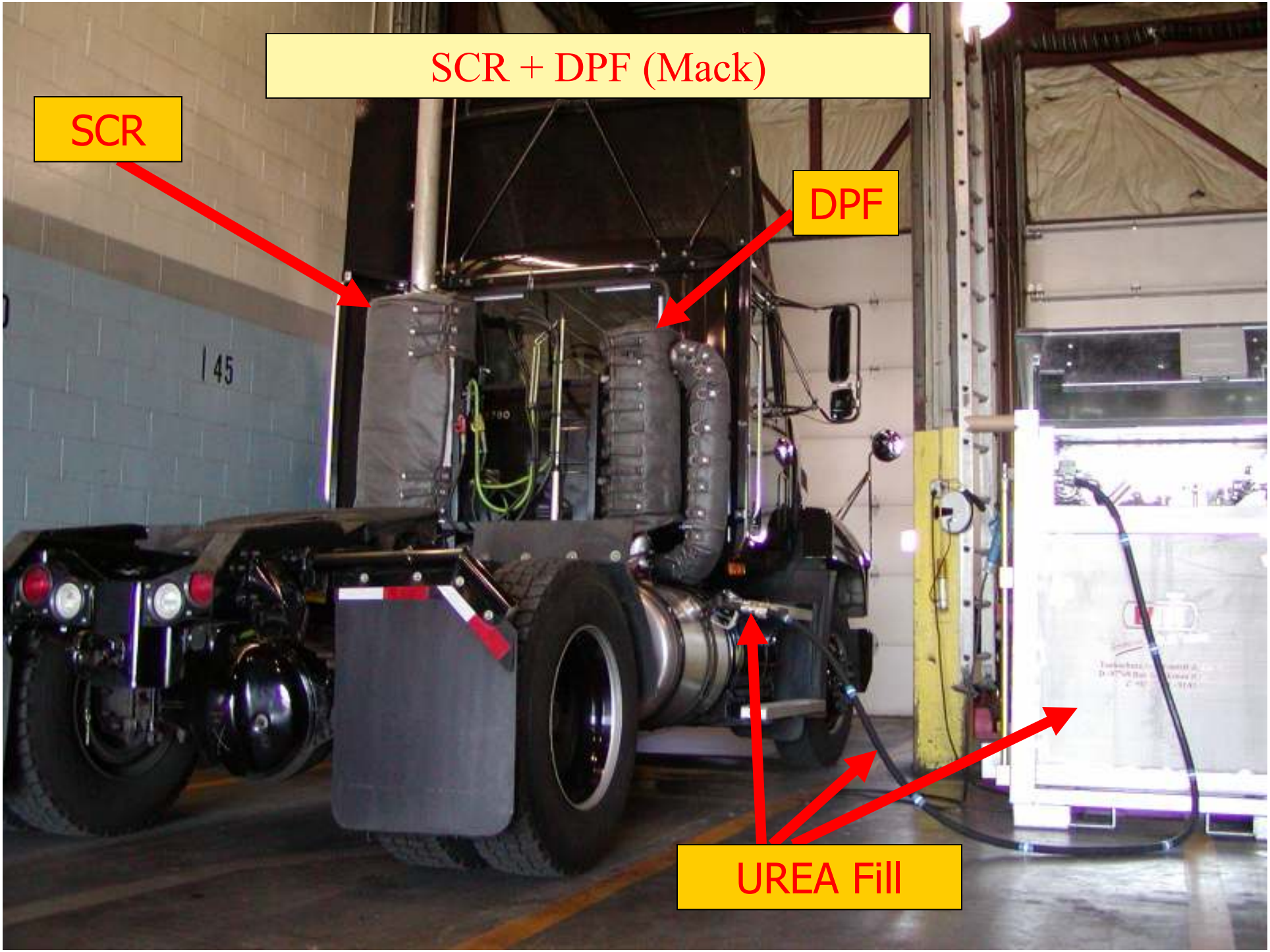
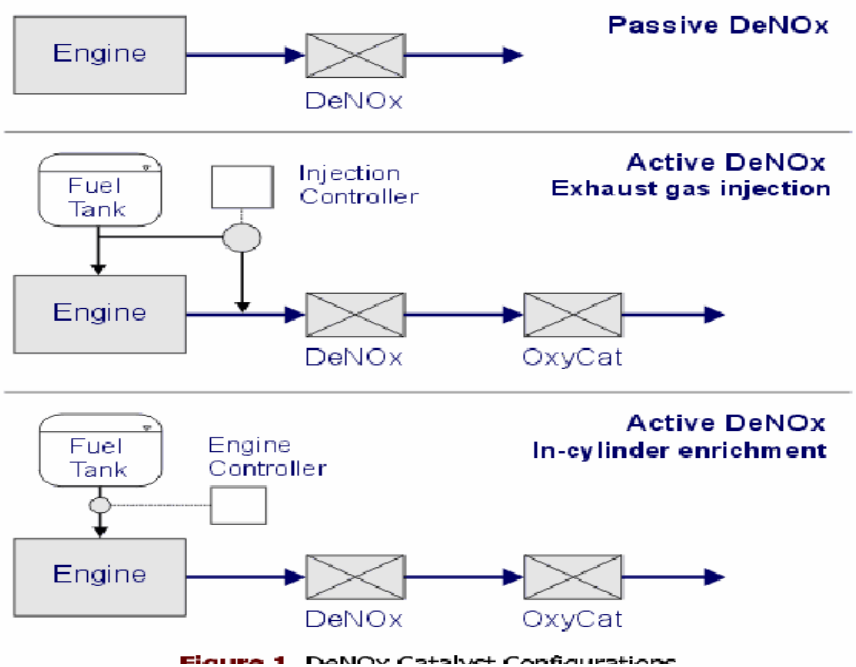


Figure 7. Open Loop Urea SCR System for Mobile Diesel Engines


SCR + DPF (Mack)
SCR
DPF
UREA Fill

Lean NOx Catalyst (LNC)

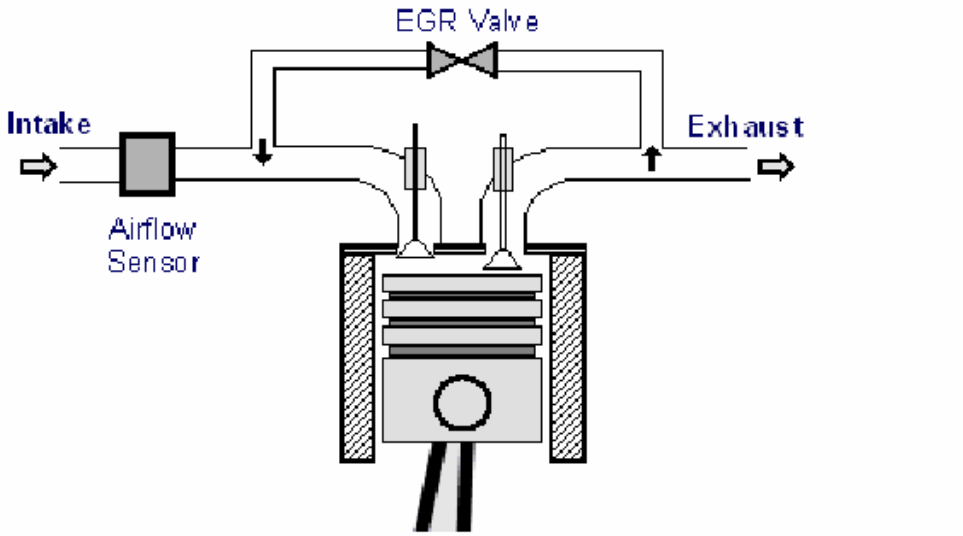
- Similar to a SCR system except the LNC injects diesel fuel into the exhaust stream and then catalyzes the reaction to reduce pollution.
- More broadly applicable, but only modest NOx reductions



$$\{HC\} + NO_x = N_2 + CO_2 + H_2O$$

Exhaust Gas Recirculation (EGR)

- EGR devices recirculate a portion of engine exhaust back into the engine to cool peak combustion temperatures and thus reduce NOx.
- EGRs have been developed for dockside and construction equipment, and highway engines.
- Typical reductions NOx (40-50%)



Repair/Rebuild

- Engines that are properly maintained and tuned perform better and typically emit less particulate matter and other pollutants.
- Rebuilding an engine can also significantly lower emissions in some cases and can be a cost effective option for high value equipment.
- Unless engines are properly maintained, other measures to reduce emissions may be futile.
- Properly maintained or recently rebuilt engines lower emissions by burning fuel more efficiently and can reduce operation costs through improved fuel economy and extended engine life.

Repower

- Repower refers to replacing an older engine with a newer, cleaner engine or replacing a diesel engine with one that can use alternative fuels.

- Where appropriate, a repower can also include substituting a cleaner highway engine for a nonroad engine.

Replace

- Replacing entire vehicles or machines may be the best option for equipment that is nearing the end of its useful life or was manufactured before stringent emissions standards were put in place.

- Port of NY/NJ – acquiring the cleanest available technologies
  - Calculated air emissions from 2002 thru 2004.
  - Although number of pieces of equipment up 19%, operating hours up 5%, and the total number of containers up 25%,
  - fuel savings 20%
  - overall emission estimates tons per year have decreased

  NOx - 31% reduction
  VOC - 32% reduction
  CO - 32% reduction
  PM - 32% reduction (10 ppm)
  SO2 - 35% reduction

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Key Considerations for Retrofit Programs

Consideration the following

- Retrofit Technology Checklist
  - Emissions Targeted
  - Engine Condition and Age
    - Perform maintenance
    - The condition of the engine is an important factor in making a decision whether to install retrofit control technology
    - How long vehicle/equipment is going to remain in service
    - Retrofit at the time of engine rebuild can be advantageous
    - Retire/Replace
  - Size
    - For filter retrofit, one must consider: vehicle application, exhaust temperature (duty cycle), engine-out PM emissions, fuel sulfur level, and the regeneration strategy to be followed

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Consideration the following …

- Retrofit Technology Check List
  - Model Year
    - Generally, only 1994 and newer should get PM filters
    - Some newer engines came with DOCs from the factory
  - Size
    - Properly sized control systems ensure low back pressure and maximum performance
  - Vehicle Integration
    - Space, accessibility and exhaust temperature are important vehicle integration issues
    - Devices are often installed in-line or as a muffler replacement

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Consideration the following …

- Retrofit Technology Check List (cont.)
  - Fuel Type
    - For PM control, <15 ppm sulfur fuel allows for maximum emission control performance (even for DOCs) and best filter regeneration characteristics
  - Maintenance
    - Vehicles to be retrofitted should be properly and regularly maintained—key factor for success
    - Retrofit technologies should be maintained per their manufacturer's recommended procedures

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Frequently Asked Questions Concerning Retrofit Programs

- Costs
  - Costs depend on many factors including:
    - Number of vehicles retrofitted (sales volume)
    - Retrofit technology used (oxidation catalyst, filter, etc.)
    - Engine size (displacement)
    - Engine out emissions
    - Fuel quality
    - Exhaust temperature and duty cycle (These factors will affect which retrofit technology will be appropriate.)
  - Costs are expected to decrease as the market expands

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Frequently Asked Questions Concerning Retrofit Programs (cont.)

Technology	Cost per Device/System ($)
Diesel Oxidation Catalysts (DOC)	425 to 1,150
Diesel Particulate Filters (DPF)	3,000 to 5,500
Combined Lean NOx Catalyst/DPF Systems	5,000 to 10,000
EGR Systems	13,000 to 15,000
SCR Systems	10,500 to 50,000

Notes: DPF costs are higher for active systems and systems that include backpressure monitoring (Year 2000 data).

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Frequently Asked Questions Concerning Retrofit Programs (cont.)

- Drivability
  - Properly selected retrofit technologies do not impair driving performance
- Maintenance
  - Oxidation and lean NOx catalysts are virtually maintenance free - require only periodic inspection
  - Filters require very little maintenance (ash removal)
  - SCR maintenance, as per manufacturer's specifications
- Effects on Engine Life
  - Properly maintained engines and retrofit control systems do not shorten engine life

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Frequently Asked Questions Concerning Retrofit Programs (cont.)

- Fuel Penalties
  - Most oxidation and lean NOx catalysts have no effect on fuel consumption
  - Most filters have no effect on fuel consumption
  - Urea consumption in SCR systems results in an equivalent fuel penalty of 3-5%
  - Systems relying on fuel injection as reductant or heat typically result in 3-5% fuel penalty
  - EGR results in a 1-4% fuel penalty
- Warranties
  - Manufacturers provide various warranties as part of a purchase agreement

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Conclusions

- A wide variety of retrofit options are available for diesel engines to reduce HC, CO, PM and toxic emissions
- NOx retrofit controls are emerging
- A growing number of retrofit programs are being successfully implemented
- Technology development continues to expand the range of applications available for retrofit
- A successful retrofit program must be properly designed and implemented

Some Diesel Retrofit Web Sites

- U.S. EPA:
  - http://www.epa.gov/otaq/retrofit
- The Manufacturers of Emission Controls Association:
  - http://www.meca.org
  - Click on "Publications" to access MECA fact sheets and technical documents on diesel retrofit
- The Diesel Technology Forum:
  - http://www.dieseltechnologyforum.com/
- The California Air Resources Board's Diesel Risk Reduction Program:
  - http://www.arb.ca.gov/diesel/dieselrrp.htm

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